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(71) Applicant (*for all designated States except US*): **COCHLEAR LIMITED** [AU/AU]; 14 Mars Road, Lane Cove, NSW 2066 (AU).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **PARKER, John** [AU/AU]; 14 Mars Road, Lane Cove, NSW 2066 (AU). **EROL, Harvey** [AU/AU]; Swinburne University, John Street, Hawthorn, Victoria 3122 (AU).

(74) Agent: **MISCHLEWSKI, Darryl**; I P Strategies, PO Box 1254, Camberwell, Victoria 3124 (AU).

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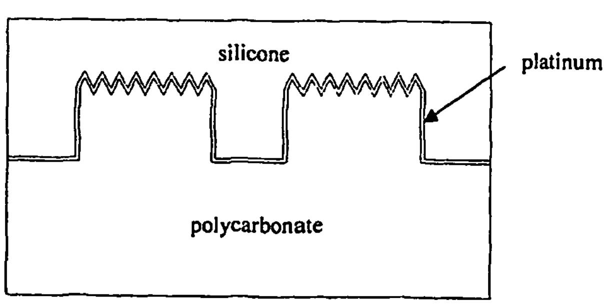
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: THIN FLEXIBLE CONDUCTORS



(57) Abstract: A thin flexible electric conductor for use in implantable devices such as cochlear implants, consists of a conductive metal layer coated on a flexible three dimensionally textured surface so that the current capacity of the conductor is increased relative to the current capacity of a conductor of the same size that is not on a three dimensional surface. The flexible substrate is treated to form a three dimensional surface such as with corrugations and a conductive layer is deposited onto the surface.

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THIN FLEXIBLE CONDUCTORS

Field of the invention

This invention relates to the fabrication of conductors in micro devices particularly implantable devices.

Background to the invention

In micro devices and implantable devices where space is at a premium conductors need to be small, flexible and yet with a cross section large enough to carry sufficient current.

USA patent 5403700 discloses a biocompatible thin film electrical component formed by depositing a metal conductor onto a polyamic acid substrate and depositing a separate insulating layer onto the conductor.

USA patent 5888577 discloses an electrode deposited on the outer surface of a catheter which does not impede the flexibility of the catheter.

USA patent 5634462 discloses a corrugated cuff electrode for nerve implantation.

USA patent 5720099 is directed to an implantable electrode assembly formed using photolithography by depositing electrode pads onto a sacrificial layer, adding wires to the pad, embedding the pads and wires in a carrier and removing the sacrificial layer.

With implantable devices, in particular cochlear implants, an implantable stimulator unit is often positioned remote from the region to be stimulated, such as in a recess in the skull, whilst the stimulating electrodes are positioned within the cochlear to apply the appropriate stimulation. Each of the electrodes positioned within the cochlea, the number of which can vary, require electrical connection to the electronic circuitry housed in the stimulator unit. This electrical connection has traditionally been in the form of a wire welded at one end to the stimulator unit and at the other end to the stimulating electrode, with each of these wires bundled together to form a lead connecting the stimulating electrode array to the stimulator unit.

In providing such a means of connection it is important that such a lead is as thin and flexible as possible, to allow for easy manipulation and positioning of the electrode array during implantation as well as to accommodate any

geometrical changes in the region of implantation over the patient's life. As the number of stimulating electrodes increases, and hence the number of conducting wires increases, so too does the stiffness, and size of the connecting lead and electrode array. Further, as in the case of cochlear implants, the area within the cochlea which receives the stimulating electrode array is of a particularly small size and shape, and as such the array needs to be of a shape that is as unobtrusive as possible on the sensitive structures of the cochlea.

In this regard there is a need to reduce the overall size of the conducting elements to reduce the size of the stimulating electrode array, so that it can be inserted into small spaces, such as the human cochlea, and which is flexible and easy to handle. However whilst the size of the conducting element is to be reduced, it is importance that the impedance of the conducting element is not increased, such that efficient electrical conduction is maintained. Therefore there is a need to provide a conductor that must support a minimum amount of current and voltage without a substantial increase in the elements impedance.

It is an object of this invention to provide a flexible conductor that meets the requirements for conductors in cochlear implants by decreasing size without increasing impedance.

Brief Description of the invention

To this end the present invention provides a flexible conductor consisting of a conductive layer on a flexible substrate in which the conductive layer forms a three dimensional surface so that the current capacity of the conductor is increased relative to the current capacity of a conductor of the same size that is not on a three dimensional surface.

The three dimensional shape may be corrugations, textured or concertina shapes that maximise cross sectional area for a given external size. The term textured means any three dimensional surface effect which increases surface area. Texturing may be achieved by embossing, corrugating or moulding.

The three dimensional conductive surface is formed on a 3 dimensional surface of a flexible substrate by any suitable surface deposition technique.

In another aspect this invention provides a flexible conductor consisting of a conductive layer on a flexible substrate in which the flexible substrate has been

shaped to form a three dimensional surface and a conductive layer has been formed on the substrate surface.

The flexible substrate is preferably silicone which serves as electrical insulation around the conductor. An example of a typical application of the present invention is for a cochlear hearing implant. More specifically, the present invention can be applied to the conductors connecting the stimulating pads of a cochlear implant to the electronics housed in an implanted stimulator housing.

In a further aspect the present invention provides a method of forming a conductor in which a conductive metal layer is deposited onto a moulded three dimensionally textured surface and a flexible electrically insulating substrate is coated on to the metal surface.

The fabrication methods used can be any combination of known metal deposition and photo lithographic methods. These methods are adaptable to automated manufacturing with a consequent reduction in costs, production time and skill required.

This invention preferably uses a technique for fabrication using a selection of the following thin film processes:

- laser micromachining
- thin film deposition techniques (electroplating, electroless plating, sputtering, CVD, PVD etc..)
- moulding
- sacrificial layers
- chemical/electrical dissolution
- electrical debonding
- lift-off layers
- polishing liquid nitrogen cooled flexible substrate
- and laser patterning

Detailed Description of the invention

The developed technique for fabrication of textured thin film flexible conductors on flexible substrates involves one or more of the following steps:

Step 1: Use of laser micromachining, chemical etching, plasma etching or other lithographic patterning methods to machine a mould with surfaces of dimensions equal to the desired conductor dimensions, such surfaces being recessed or raised (with respect to a reference mould surface) if necessary, and being textured or corrugated if necessary.

Step 2: If desired, use of a thin film deposition technique to deposit a seed layer on the mould and to electroplate the aforementioned seed layer, to thereby produce a complementary mould.

Step 3: If desired, application of a lift-off layer (eg sticky tape) to the mould and laser patterning to remove the lift-off layer in the region of conductors.

Step 4: If desired, use of a thin film deposition technique to coat the mould with a thin film sacrificial layer.

Step 5: If desired, use of a thin film deposition technique to coat the mould with platinum thin film.

Step 6: If desired, use of laser patterning or polishing or lift-off layer removal or any other means to electrically isolate the conductors by removing unwanted platinum film from the mould.

Step 7: Use of the mould to mould the silicone rubber.

Step 8: Separation of moulded silicone rubber from the mould, using mechanical force or electrical/chemical dissolution of sacrificial layer or electrical debonding or cryogenic shock or any other means.

Step 9: If desired, application of a lift-off layer (eg sticky tape) to the moulded silicone and laser patterning to remove the lift-off layer in the region of conductors.

Step 10: If desired, use of a thin film deposition technique to coat the moulded silicone rubber with platinum thin film.

Step 11: If desired, use of polishing or laser patterning or lift-off layer removal or any other means to electrically isolate the conductors by removing unwanted platinum film from the moulded rubber.

Step 12: Application of another layer of silicone to encapsulate the isolated conductors.

The developed technique thus has many alternative embodiments, each being defined by a fabrication route that is characterised by a selection of the above steps.

In the drawings:

figure 1 is a cross sectional view of a machined polycarbonate mould and illustrates step 1;

figure 2 is a cross sectional view of a complementary nickel mould and illustrates step 2;

figure 3 is a cross sectional view of a platinum coated silicone casting and illustrates steps 7, 8 and 10;

figure 4 is a cross sectional view of a platinum coated silicone casting after polishing and encapsulation and illustrates steps 11 and 12;

figure 5 is a cross sectional view of a machined polycarbonate mould and illustrates another version of step 1;

figure 6 is a cross sectional view of silicone rubber moulded on a platinum coated polycarbonate mould and illustrates steps 5 and 7;

figure 7 is a cross sectional view of a platinum coated silicone casting after polishing and encapsulation and illustrates steps 8, 11 and 12;

figure 8 a cross sectional view of a machined polycarbonate mould and illustrates another version of step 1;

figure 9 is a cross sectional view of a complementary copper mould and illustrates another version of step 2;

figure 10 is a cross sectional view of silicone rubber moulded on a platinum coated copper mould and illustrates steps 5 and 7;
figure 11 is a cross sectional view of a platinum coated silicone casting after polishing and encapsulation and illustrates another version of steps 8, 11 and 12

The following examples illustrate three of many possible preferred embodiments of the developed technique.

Example 1 – Direct Approach

a) Excimer laser is used to micromachine a polycarbonate mould consisting of recessed corrugated surfaces. Each surface is 20 cm long (desired length of flexible conductor) and 40 microns wide (desired width of flexible conductor) and recessed by 70 microns. Each surface consists of eight triangular corrugations or grooves, each being 5 microns wide and 5 microns deep. Refer to Figure 1.

b) Physical vapour deposition (PVD) is used to deposit a nickel seed layer onto the aforementioned polycarbonate mould. The seed layer is electroplated to build up a complementary nickel mould. Thermal techniques are used to separate the two moulds. Refer to Figure 2.

c) The nickel mould is used to make a silicone rubber casting. Mechanical force is used to separate the casting from the mould. DC or RF Magnetron sputtering, or electron beam evaporation is used to deposit a platinum seed layer onto the silicone casting. The seed layer is electroplated to build up the platinum layer to a thickness of a few microns. Refer to Figure 3.

d) The platinum-coated silicone casting is cooled with liquid nitrogen and polished, to remove unwanted platinum and electrically isolate the conductors. Another layer of silicone is applied to encapsulate the conductors. Refer to Figure 4.

e) Assuming the platinum film is 2 microns thick, the cross-sectional area of each conductor in the region of the corrugations is approximately 178 square microns. This is more than adequate for existing requirements.

Example 2 – Lift-Off Approach

a) Excimer laser is used to micromachine a polycarbonate mould consisting of raised corrugated surfaces. Each surface is 20 mm long (desired length of conductor) and 40 microns wide (desired width of conductor) and raised by 70 microns. Each surface consists of eight triangular corrugations, each corrugation being 5 microns wide and 5 microns deep. Refer to Figure 5.

b) Electroless plating is used to deposit a poorly adhered platinum seed layer onto the polycarbonate mould. The seed layer is electroplated to build up the platinum layer to a thickness of a few microns. Silicone adhesive is applied to the platinum film. The silicone rubber is moulded on the platinum-coated mould. Refer to Figure 6.

c) Mechanical force is used to remove the silicone casting together with the platinum film from the mould. The platinum-coated silicone casting is cooled with liquid nitrogen and polished, to remove unwanted platinum and electrically isolate the conductors. Another layer of silicone is applied to encapsulate the conductors. Refer to Figure 7.

Example 3 – Sacrificial Layer Approach

a) Excimer laser is used to micromachine a polycarbonate mould consisting of recessed corrugated surfaces. Each surface is 20 mm long (desired length of conductor) and 40 microns wide (desired width of conductor) and recessed by 70 microns. Each surface consists of eight triangular corrugations, each corrugation being 5 microns wide and 5 microns deep. Refer to Figure 8. This method also applies to the case where the height of the corrugations is almost equal to the depth of the trench that is where the conductors are laid onto a series of ribs or ridges.

b) Physical vapour deposition (PVD) is used to deposit a copper seed layer onto the aforementioned polycarbonate mould. The seed layer is electroplated with copper to make a complementary copper mould. Thermal techniques are used to separate the two moulds. Refer to Figure 9.

c) The copper mould is electroplated with a layer of platinum, a few microns thick. Silicone adhesive is applied to the platinum, and the silicone is moulded. Refer to Figure 10.

d) The copper is then chemically or electrically dissolved, leaving the platinum-coated silicone casting. The platinum-coated silicone casting is cooled with liquid nitrogen and polished, to remove unwanted platinum and electrically isolate the conductors. Another layer of silicone is applied to encapsulate the conductors. Refer to Figure 11.

The conductors of the present invention, can be incorporated into a lead for use in an implantable device, such as a cochlear implant or other implantable device delivering electrical stimulation from a stimulator unit to an electrode. The lead is made from a flexible, insulating material, that is compatible with the body, for example a silicone rubber. A number of conductor elements extend through the lead and are connected at one end of the lead to an implantable stimulator unit which is capable of generating electrical signals and delivering the electrical signals to be carried by any one of the conductor elements. At the other end of the lead the conductor elements can be connected to a stimulating electrode to allow for the delivery of the electrical signal to the tissue surrounding the stimulating electrode in the form of electrical stimulation. It can be appreciated that the present invention allows for the size of the lead and the associated electrode array to be significantly minimised without increasing the impedance of the conducting elements. It should also be appreciated that any number of conducting elements could be implemented and arranged in any orientation and still fall within the scope of the present invention. It should also be appreciated that the lead could have any cross sectional shape, for example circular, rectangular, square or oval, and still fall within the scope of the present invention.

From the above description it can be seen that this invention provides a unique conductor for use in implantable devices. Those skilled in the art will understand that in accordance with the concepts taught by this invention many individual embodiments are possible.

CLAIMS

1. A flexible conductor consisting of a conductive layer on a flexible substrate in which the conductive layer has been shaped to form a three dimensional surface so that the current capacity of the conductor is increased relative to the current capacity of a conductor of the same size that is not on a three dimensional surface.

2. A flexible conductor consisting of a conductive layer on a flexible substrate in which the flexible substrate has been shaped to form a three dimensional surface and a conductive layer has been formed on the substrate surface.

3. An implantable device incorporating a thin flexible conductor consisting of a conductive layer on a flexible substrate in which the flexible substrate has been shaped to form a three dimensional surface and a conductive layer has been deposited on the substrate surface

4. An implantable device as claimed in claim 3 wherein the substrate is corrugated.

5. A method of forming a conductor in which a conductive metal layer is deposited onto a moulded three dimensionally textured surface and a flexible electrically insulating substrate is coated on to the conductive metal surface.

6. A method as claimed in claim 5 wherein the mould surface is coated with a layer of flexible insulating material onto which the metal layer is deposited.

7. A method as claimed in claim 5 wherein the mould surface is corrugated.

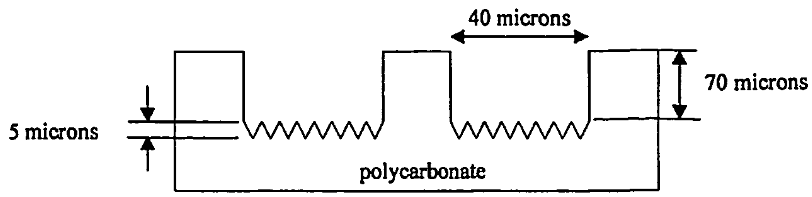

Figure 1

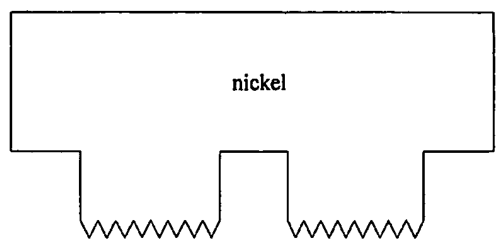

Figure 2

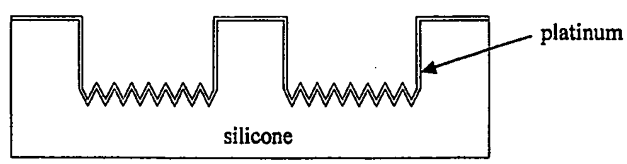

Figure 3

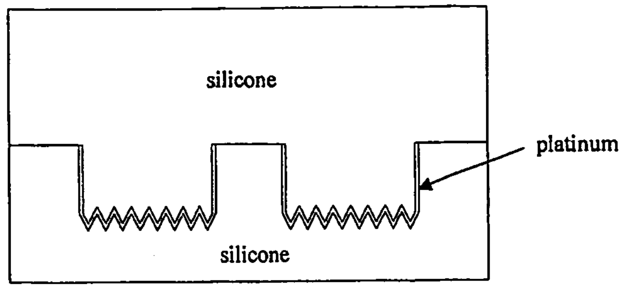

Figure 4

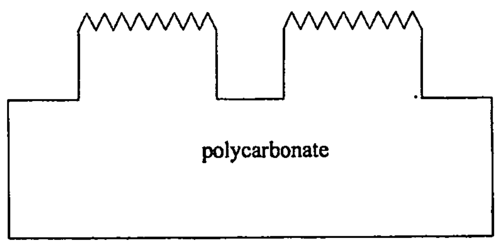

Figure 5

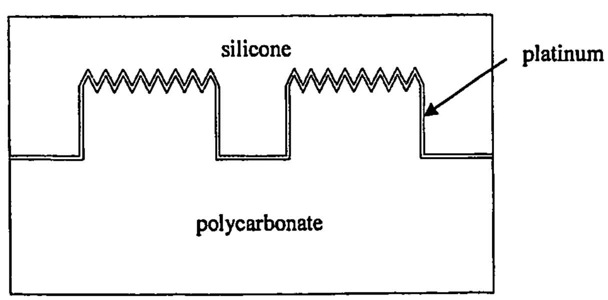

Figure 6

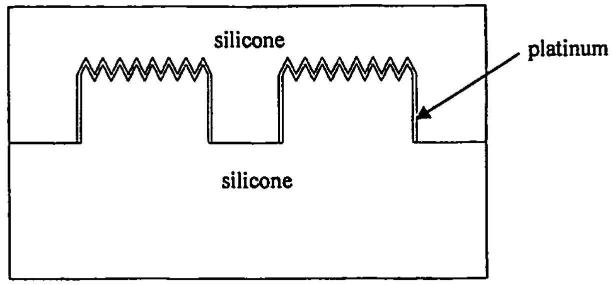

Figure 7

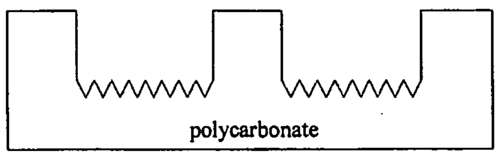

Figure 8

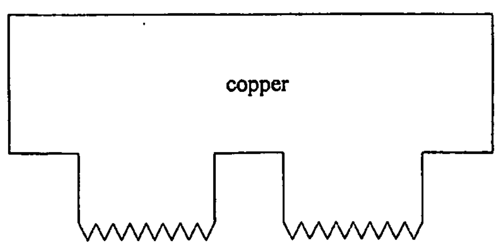

Figure 9

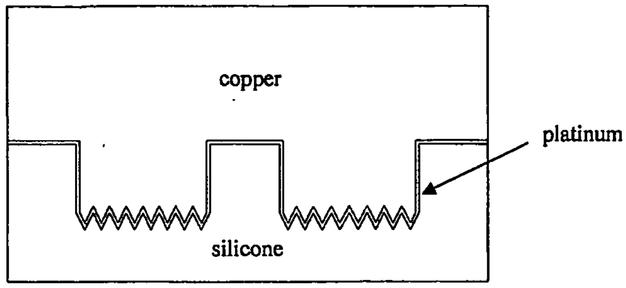

Figure 10

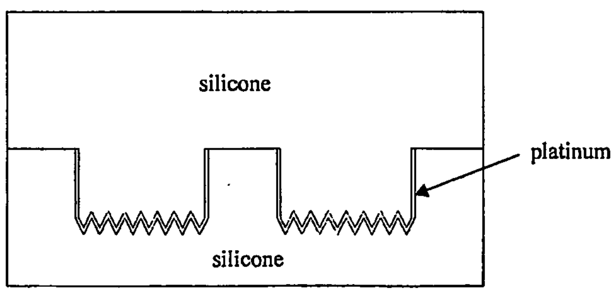

Figure 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU02/01505

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. 7: H01B 5/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC H01B 5/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI,JAPIO, IFIPAT: film,layer,conductor,cable,electrode,wire,thin,ribbon,corrugate,texture,irregular,wavy,zigzag,zig zag,serrate,3 D,3 dimensional,sinuous,sinusoidal,area,cross section,profile,pattern,shape,flexible,pliable,pliant

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2288531 A (MATTEI) 25 June 1976 entire document	1,2
X	US 4367755 A (BAILEY) 11 January 1983 abstract, column 3, lines 4-11	1,2
A	EP 1102355 A2 (JAPAN AVIATION ELECTRONICS INDUSTRY LTD) 23 May 2001 abstract	

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 December 2002	10 DEC 2002

Name and mailing address of the ISA/AU

AUSTRALIAN PATENT OFFICE
PO BOX 200, WODEN ACT 2606, AUSTRALIA
E-mail address: pct@ipaustralia.gov.au
Facsimile No. (02) 6285 3929

Authorized officer

MANO RAMACHANDRAN
Telephone No : (02) 6283 2166

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 112646 A (EXXON RESEARCH AND ENGINEERING COMPANY) 4 July 1984 abstract	
A	US 4808462 A (YABA et al) 28 February 1989 abstract	
A	Patent Abstracts of Japan, JP 2000-347592 A2 (FUJITSU LTD) 15 December 2000 abstract	
A	Derwent Abstract Accession No. 2002-007978/01, Class X12, JP 2001-291436 A2 (SHOWA ELECTRIC WIRE & CABLE) 19 October 2001 abstract	

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 112646 A (EXXON RESEARCH AND ENGINEERING COMPANY) 4 July 1984 abstract	
A	US 4808462 A (YABA et al) 28 February 1989 abstract	
A	Patent Abstracts of Japan, JP 2000-347592 A2 (FUJITSU LTD) 15 December 2000 abstract	
A	Derwent Abstract Accession No. 2002-007978/01, Class X12, JP 2001-291436 A2 (SHOWA ELECTRIC WIRE & CABLE) 19 October 2001 abstract	